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1 **Selecting species for passive and active riparian restoration in Southern Mexico**

2 Paula Meli^{1,3}, Miguel Martínez-Ramos² and José M. Rey-Benayas³

3 ¹Natura y Ecosistemas Mexicanos A.C., San Jacinto 23-D, Col. San Ángel, México D.F., CP
4 01000, México.

5 ²Centro de Investigaciones en Ecosistemas, Universidad Nacional Autónoma de México,
6 Antigua Carretera a Pátzcuaro No. 8701, CP 58190, Morelia, México.

7 ³Universidad de Alcalá, Edificio de Ciencias, Departamento de Ecología, 28871, Alcalá de
8 Henares, Madrid, Spain.

9 Author for correspondence: P. Meli, email paula@naturamexicana.org.mx

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Abstract

In revegetation projects, distinguishing species that can be passively restored by natural regeneration from those requiring active restoration is not a trivial decision. We quantified dominance of tree species (measured by an Importance Value Index, IVI_i) and used abundance-size correlations to select those species suitable for passive and/or active restoration of disturbed riparian vegetation in the Lacandonia region, Southern Mexico. We sampled riparian vegetation in a $50 \times 10\text{m}$ transect in each of six reference (RE) and five disturbed (DE) riparian ecosystems. The species accumulating more than 50% of total IVI in each ecosystem were selected and Spearman rank correlation between abundance and diameter classes was calculated. For eight species passive restoration should be sufficient for their establishment. Other eight species necessarily should be transplanted by means of active restoration. Four species regenerate well in only one ecosystem type, so both restoration strategies could be used depending on the particular project context. Finally, three species were not important in the RE and were not selected at this first stage of our restoration project. The high number of tree species found in the RE suggests that the pool of species for ecological restoration is wide. However, sampling in both ecosystem types helped us to reduce the number of species that will require active restoration. Restoration objectives must guide the methods to implement, and perhaps in different conditions other criteria such as the dispersal syndrome or the social value could be considered in the selection of species.

Key words: indicators, Lacandonia, natural regeneration, rainforest, recovery.

Introduction

An aim of ecological restoration is to reestablish in a degraded or destroyed ecosystem the characteristic species assemblage and appropriate community structure occurring in the reference ecosystem (SER 2004). Many tropical and humid temperate ecosystems can recover

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with little or no human intervention when the soil has not been severely degraded (González-Espinosa et al. 2007). In these cases, “cessation of activities that are causing degradation or preventing recovery” (passive restoration, Kauffman et al. 1997) is enough to drive ecosystem recovery, and it can be considered the first step in ecological restoration (Rey-Benayas et al. 2008). However, although passive restoration may be sometimes sufficient for some species, others need active restoration. Revegetation -the deliberate introduction of native species- is one of the tools most frequently used in ecological restoration, but it is usually time and economically consuming. Therefore, distinguishing species that can be passively restored by natural regeneration from those species requiring active restoration can greatly reduce the cost and effort of a restoration project. However, making this determination is not trivial. Our main goal is selecting species for passive and active restoration of riparian vegetation in the Lacandonia region, Southern Mexico in the early stage of this restoration project.

Methods

The study was conducted in Marqués de Comillas Municipality (16°54[′] N, 92°05[′] W), in the Lacandonia region, Southern Mexico. Mean annual precipitation is about 3,000 mm and a short dry season (< 100 mm month⁻¹) occurs between January and April (Martínez-Ramos et al. 2009). Humans settled this region during the early 1970s and former rainforest has been extensively converted to agricultural fields (De Jong et al. 2000).

Our reference ecosystem (RE) consisted in six pristine riparian areas. Our disturbed ecosystem (DE) includes five areas that were completely deforested and later abandoned (3 to 10-year-old). Presently DE areas are covered by secondary riparian vegetation. In each study area we sampled riparian vegetation in a 50 × 10 m transect, where we measured the height and diameter at breast height (dbh) of all trees with dbh > 1.5 cm. The dbh data was converted to basal area values using $\pi \times (\text{dbh} \times 0.5)^2$. For each transect and species, we calculated an Importance

Value Index (IVI_i) as the sum of the species relative density, relative frequency and relative basal area divided by three (Curtis & McIntosh 1951). Our analysis was restricted to those species with the greatest IVI_i and that together covered more than 50% of total IVI in each ecosystem. Per transect we calculated for each species their abundance (N_i , number of stems of species i per transect) in each of ten dbh classes (every 5 cm each). Then, for each transect and species, we calculated the correlation (Spearman rank correlation, r_s) between abundance [$\log(N_i + 1)$] and the mid-point of the dbh classes (hereafter called abundance-size correlation). A high regeneration potential is represented by a diminishing number of individuals as diameter sizes enlarges. This trend will result in a high and negative correlation (high availability of small sized trees), and therefore an acceptable potential for passive establishment of the species. A positive or non-significant correlation (lack of small sized trees) means that the species does not establish naturally and therefore it needs to be actively restored.

Results

A total of 115 species were found in RE, while a total of 97 species were found in DE. The first fifteen species accounted for 54% and 51% of the total IVI in the RE and DE, respectively. From these species, five species were common to RE and DE (*A. leucocalyx*, *A. hottlei*, *C. schiedeana*, *D. guianense*, and *Ficus* sp.), and two were absent in the RE. We therefore characterized 23 species for assessment of restoration (Table 1).

Eight species showed significant and negative abundance-size correlation ($r_s < -0.6$, $p < 0.05$) in both ecosystem types suggesting that passive restoration could be sufficient for their successful establishment (Table 1). At the other extreme, eight species were either absent in DE or the abundance-size correlation was not significant and thus such species should be introduced by active restoration. Four species regenerate well in only one ecosystem type, so either strategy could be used depending on the particular project context. Finally, the three species that were

1 not included in the first fifteen species with high IVI_i in RE were not selected for restoration
2 (but they can be used, for example, for nursery propagation).

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11 **Discussion**

12 The interpretation of the IVI_i and the abundance-size correlations allowed us reaching a
13 preliminary list of 20 species with potential use for the restoration of riparian vegetation in
14 Lacandonia and provide recommendations on possible restoration strategies for particular
15 species. The high number of tree species found in RE shows that the pool of species for
16 ecological restoration is wide and sampling in both ecosystem types helped us to develop a
17 comprehensive list of species based on their abundance and size. However, the predictive
18 potential of the abundance-size correlations could be limited by the small sample sizes. Low
19 species abundances in highly diverse humid tropics difficult to perform accurate correlations
20 without more data. Furthermore, the predictive capacity of the abundance-size correlations could
21 decrease as the age of DE increases and its species composition starts to resemble that of the
22 RE.

23 Our method did not target some pioneer species (*S. parahybum*, *Piper* sp.) because their
24 ability to establish naturally in degraded areas. Such pioneer species may not be the most
suitable species in economic terms when degradation is not very severe, as in our study. Where
land degradation is severe, as in degradation caused by mining (Sharma & Sunderraj 2005), or
with specific problems such as high erosion on steep slopes (dos Santos et al. 2008), the use of
pioneer species adapted to grow on disturbed or degraded ecosystems could be recommended
for active restoration.

We concluded that our method is useful to select species for restoration due to its relative
low cost and ease that makes it accessible to different stakeholders. It could be applied in other

ecosystems where trees are dominant, but its use would be limited in grasslands or other ecosystems where species regeneration is difficult to estimate. Finally, as in any restoration project, the method selected will depend on the main objectives. In different conditions other criteria could be considered in the selection of species, including adaptive capacity for different soils (Sharma & Sunderraj 2005), social values (*cf.* Moreno-Cassasola & Paradowska 2009), and attributes such as dispersal syndromes (Sansevero et al. 2009). Rare species such shrubs and herbaceous species are also important, but not necessarily at early stages of restoration.

Implications for Practice

- At early stages of restoration of ecosystems dominated by trees, the combination of species dominance indexes (e.g. IVI_i) and abundance-size correlations could be used to select a preliminary list of species suitable for passive or active restoration.
- Species that establish by natural regeneration could be used in passive restoration actions when ecosystems are not severely degraded.

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1 Table 1. Species Importance Value Index (IVI) and Spearman rank correlation coefficient (r_s) in reference and disturbed riparian
2 ecosystems of 23 native tree species found in the Lacandonia region, and recommendation for restoration (passive, active, or non-
3 selected –NS- species for restoration).

Species	Family	Reference ecosystem			Disturbed ecosystem			Restoration recommendation
		IVI	r_s	p	IVI	r_s	p	
<i>Ficus</i> sp.	Moreaceae	10.145	0.5	0.1173	2.212	-0.1	0.7699	active
<i>Cojoba arbórea</i>	Mimosoideae	6.264	-0.2089	0.5376	0.504	-0.4	0.2229	active
<i>Dialium guianense</i>	Caesalpinoideae	5.305	-0.485	0.1305	5.018	0.051	0.8817	active
<i>Protium</i> sp.	Burseraceae	4.781	-0.7862	0.0041	2.365	-0.7862	0.0041	passive
<i>Ampelocera hottleii</i>	Ulmaceae	4.394	-0.5625	0.0717	1.233	-0.7747	0.0051	passive
<i>Brosimum alicastrum</i>	Moreaceae	3.494	-0.2293	0.4975	0.485	-0.5	0.1173	active
<i>Brosimum costarricanum</i>	Moreaceae	2.854	-0.2132	0.5291	.	.	.	active
<i>Guarea glabra</i>	Meliaceae	2.851	-0.6742	0.0229	0.356	-0.7659	0.006	passive
<i>Croton schiedeanus</i>	Euphorbiaceae	2.316	-0.7551	0.0072	5.039	-0.917	<.0001	passive
<i>Pouteria durlandii</i>	Sapotaceae	2.305	-0.887	0.0003	1.201	-0.6068	0.0478	passive

<i>Calophyllum brasiliense</i>	Clusiaceae	1.995	-0.4842	0.1313	0.622	-0.5	0.1173	active
<i>Nectandra sleneri</i>	Lauraceae	1.898	-0.7862	0.0041	.	.	.	active
<i>Albizia leucocalyx</i>	Mimosoideae	1.892	-0.8522	0.0009	4.223	-0.2582	0.4433	passive / active
<i>Vochysia guatemalensis</i>	Vochysiaceae	1.864	-0.1195	0.7263	2.004	-0.3772	0.2528	active
<i>Eugenia mexicana</i>	Myrtaceae	1.777	-0.8291	0.0016	0.831	-0.5	0.1173	passive / active
<i>Castilla elastica</i>	Moreaceae	1.554	-0.7974	0.0033	3.648	-0.7862	0.0041	passive
<i>Spondias mombin</i>	Anacardiaceae	0.885	-0.5164	0.1039	3.235	-0.8449	0.0011	passive
<i>Inga vera</i>	Mimosoideae	0.859	-0.8315	0.0015	3.896	-0.6116	0.0456	passive
<i>Lonchocarpus guatemalensis</i>	Papilionoideae	0.725	-0.7659	0.006	2.956	-0.5745	0.0645	NS
<i>Cecropia peltata</i>	Cecropiaceae	0.635	-0.7946	0.0035	4.779	-0.8318	0.0015	passive
<i>Orthion subsessile</i>	Violaceae	0.548	-0.6607	0.0269	2.068	-0.7833	0.0043	passive
<i>Piper sp.</i>	Piperaceae	0.278	-0.5	0.1173	2.275	-0.7862	0.0041	NS
<i>Schizolobium parahybum</i>	Caesalpinoideae	0.117	-0.1	0.7699	4.306	-0.8102	0.0025	NS